A Status Report on Solar Energy Utilization in the State of Florida

1975

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A STATUS REPORT ON SOLAR ENERGY UTILIZATION IN THE STATE OF FLORIDA

BY

HENRY MICHAEL ARMSTRONG
B.S., United States Air Force Academy, 1965

RESEARCH REPORT

Submitted in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Studies Program of Florida Technological University

Orlando, Florida
1975
ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. Ronald D. Evans for his suggestions and assistance in conducting this investigation.

Appreciation is expressed to Pratt & Whitney Aircraft and the Florida Research and Development Center for providing the financial aid necessary to take the requisite courses.

A special appreciation is expressed to the author's family for their patience and understanding throughout the course of this study. It is for past proof and future faith in her encouragement that this dissertation is dedicated to the author's wife, Shelly.
ABSTRACT

The current energy crisis has pointed out the need for alternative, non-depletable sources of power. Solar energy would appear to be a likely source of such power for the state of Florida where the average home receives enough of this energy to supply all of its heating and cooling needs during the course of the year.

Energy consumption profiles for Florida reveal that almost one-quarter of all energy is consumed within the residential-commercial section for basic heating and cooling. Additionally, the state is, essentially, totally dependent on petroleum and natural gas for its energy supply.

Solar energy has been used in many applications for hundreds of years, but its proliferation has been prevented by the cheapness and availability of other fuels. This, in turn, has hindered the expansion of solar technology. As a result, there are economic and sociologic problems to be overcome. In an attempt to solve these problems, a comprehensive program of basic research is being funded by the national government.

The early studies made by outside researchers and the initial reports issued by the government reveal that solar systems are both economically and technically feasible.
However, in Florida, the system must be used for both heating and cooling for it to be economical.

Florida is an ideal area for the use of solar energy because of its climate. But, a simple calculation of solar potential shows that it will be at least 40 years before this energy can make a meaningful impact if restricted to basic heating and cooling using existing thermal technology. It is concluded that significant strides in the use of solar power will occur only when it can be converted to electricity.

Recommendations are made which could help solve the energy crisis both locally and nationally.
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HOW BIG IS ONE TRILLION BTU?

The following description was obtained from the Florida Energy Committee [1], a group which makes reports and recommendations on energy and energy policy in Florida to the Governor and the Florida Legislature.

An average U.S. automobile getting 13.5 miles per gallon driving across the nation once a week would need almost 16 years to use one trillion BTU's worth of gasoline and would travel about 2.5 million miles.

One trillion BTU's of fuel converted into electricity in Florida's power plants would light a 100-watt bulb for 100,000 years. This electricity would also serve the electrical needs of the average Florida household for 80 centuries.

One trillion BTU's added to Lake Okeechobee would raise its temperature approximately 38°F.

The energy content in the oil carried by one 25,000-deadweight-ton tanker is approximately one trillion BTU's. This size tanker is used in coastal shipping and is

---

1Numbers in brackets refer to similarly numbered references in the bibliography.
typically 600 feet long and draws 32 feet of water. At $10 per barrel, this cargo is worth $1.7 million.

In 1972, the state of Florida used one trillion BTU's every 5 hours and 15 minutes.
CHAPTER I

INTRODUCTION

The United States has recently experienced an energy crisis unparalleled in its history. Brought to the forefront by the Arab oil boycott, this turn of events has been precipitated by the environmental movement and its concern with the effects of increased pollution resulting from the continued rise in energy demand. More petroleum products and larger refinery capacities were suddenly and unexpectedly needed as users switched to low-ash, low-sulfur fuels. In particular, the demand for distillate oil was much greater than anticipated as power plants converted to oil from coal, electric utilities turned to oil-burning gas turbines in place of nuclear reactors, and automobile mileage decreased with the addition of new safety and anti-pollution equipment.

The problem . . . has many components. These include the United States and the world's escalating demand towards those fuels in shortest supply—petroleum and natural gas; the mismatch between the location of refining capacity and the location of demand centers; the economic and political repercussions of the sudden change in availability of Middle East petroleum; the declining domestic production as a fraction of use in the United States; and the present unavailability of alternative energy sources capable of bridging the energy gap [1].
In 1850, the per capita energy consumption of the United States was approximately half of what it is today [2]. Through the intervening years, as the forests were cut and the population grew, fields of coal, oil, and natural gas were discovered, and the nation gradually switched from wood to fossil fuels as its primary source of energy. Today, this growth in energy consumption continues. In the United States, the demand for electricity is doubling every ten years, the demand for energy every twenty; Florida's rates are double these. In 1972, this country devoured 36 percent of the world's energy despite having only 6 percent of the world's population [3].

Worldwide energy consumption patterns reflect those of the United States; therefore, it is logical to conclude that eventually fossil fuels will become scarce or exhausted. The predicted time of such depletion is dependent on many factors, such as population growth, new technology, future fossil fuel discoveries, etc.; but, it is apparent that such a state of affairs must transpire if present energy patterns endure. Power cannot continue to be generated from fossil fuels, fuels which are consumables and are not readily replenished by nature. Alternate non-consumable sources of energy must be developed to preserve these resources.

Solar energy is a non-depletable resource, which might readily substitute for fossil fuels in many applications. Of the many alternative sources of energy
currently being studied, such as ocean thermal gradient, wind energy conversion, and geothermal power, solar energy would appear to be the most attractive for the state of Florida.

Two primary methods for the application of incident solar radiation are under consideration. The first is "in situ" applications of solar radiation wherein solar energy is converted directly to heat and application of that heat is made at the site of collection. This type of application appears to be most likely to offer an alternative energy resource within the next few years. Applications such as solar water heating and solar air-conditioning are examples of this use. It seems likely that, if an intensive effort to develop this application is made, then within five years significant numbers of installations using solar energy could be in operation in Florida. It should be recognized, however, that it is unlikely that even within 10 years solar energy will handle more than a very few percent of total energy use within the state. This is characteristic, however, of most actions that can be taken.

The second application of solar energy would collect the energy and convert it to a transportable form such as electricity. The secondary energy would then be marketed. Most experts believe the technology for practical application of solar energy in such use is probably two decades away at the minimum. . . .

. . . The energy supply options available to Florida over which it can have significant influence, and which can have effect in the next few years appear to be quite limited. Among those, the application of "in situ" solar radiation appears to be most attractive [1].

Tybout and Löf [4] made a rough estimate which assumed that a typical house would have about 1,000 square feet of floor area and would require about 15,000 BTU's per
degree day (BTU/DD).² This representative house would experience about 4,000 degree days in a year. This, in turn, means that the house would have a heat demand of 15,000 times 4,000 or 60 million BTU's per year. The average annual U.S. solar radiation intensity is 1,400 BTU per square foot per day; therefore, 511 million BTU's will be received. Thus, it is seen that the solar energy annually falling on the roof of a typical American house is about 8.5 times as great as the annual space heat demand. It is sufficient to note that the solar energy resource is, on the average, abundant enough to encourage a deeper inquiry into the costs and practicality of its utilization. Such an inquiry is conducted in this paper.

²The number of degree days is calculated as the product \((65-t_a)\), where \(t_a\) is atmospheric average daily temperature on the Fahrenheit scale, times the number of days \(t_a\) holds. When \(t_a\) is above 65°F, it is assumed no house heating is needed.
CHAPTER II

ENERGY CONSUMPTION PROFILES

In order to be able to assess the potential uses of solar energy and to be able to define the particular areas where research should be directed, various relevant energy profiles for the state of Florida need to be characterized.

TABLE 1

TOTAL ENERGY USE IN FLORIDA BY SECTOR FOR 1972

<table>
<thead>
<tr>
<th>Sector</th>
<th>Percent of Total Energy Use in Florida</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>38.6</td>
</tr>
<tr>
<td>Residential and Commercial</td>
<td>37.4</td>
</tr>
<tr>
<td>Industrial</td>
<td>16.0</td>
</tr>
<tr>
<td>Other</td>
<td>8.0</td>
</tr>
</tbody>
</table>


As shown in Table 1, the transportation sector accounted for the largest portion of energy consumed in
Florida with 38.6 percent of the total. Since the energies utilized by this sector take the forms of various types of fuels, a breakdown of the sector by fuel, as shown in Table 2, will be of some use.

**TABLE 2**

**FUELS USED FOR TRANSPORTATION IN FLORIDA IN 1972**

<table>
<thead>
<tr>
<th>Type of Fuel</th>
<th>Percent of Sector Use</th>
<th>Percent of Total Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>74.5</td>
<td>28.8</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>16.8</td>
<td>6.5</td>
</tr>
<tr>
<td>Diesel</td>
<td>4.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Middle Distillate</td>
<td>2.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Residual Fuel</td>
<td>1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>L.P. Gas</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>


Following closely with 37.4 percent of the total energy consumed is the residential-commercial sector. Because there is no breakdown of this sector available for the state of Florida, Table 3 presents the same breakdown for the United States under the assumption that the two are fairly similar with the exception of the space heating and air-conditioning requirements. With regard to the space...
heating and air-conditioning demands, it is felt that although they are in error for Florida, because they are an average across the entire United States, the total of the two is a fairly good approximation of the sum for the state.

TABLE 3
RESIDENTIAL-COMMERCIAL SECTOR END USES FOR THE UNITED STATES

<table>
<thead>
<tr>
<th>End Use</th>
<th>Percent of Sector Use</th>
<th>Percent of Total Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Heating</td>
<td>53.6</td>
<td>18.0</td>
</tr>
<tr>
<td>Water Heating</td>
<td>11.9</td>
<td>4.0</td>
</tr>
<tr>
<td>Air Conditioning</td>
<td>7.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>6.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Asphalt and Road Oils</td>
<td>4.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Cooking</td>
<td>3.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Television</td>
<td>1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Food Freezing</td>
<td>1.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Clothes Drying</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Other</td>
<td>8.2</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Note in Table 3 that 24.5 percent of all the energy consumed in the United States was used for basic heating and cooling within the residential-commercial sector.

Table 1, page 5, shows that the industrial sector was a relatively small consumer of energy with only 16 percent of the total. This is because Florida has relatively few industries which are energy intensive; the major manufacturing industry is the frozen citrus-concentrate business. The remaining 8 percent of total energy was utilized by the local and state governments for schools, street lighting, municipal facilities, and the like.

A breakdown of the consuming sectors by energy source is presented in Figure 1 [1]. Note that petroleum products, a conglomeration of gasoline, residual fuel, middle distillate, jet fuel, and L.P. gas, represent more than 74 percent of all the energy consumed. Petroleum products also accounted for approximately 86 percent of the energy derived from the direct use of fuel and almost 59 percent of the energy used to generate electricity.

The direct use of fuel refers to the usage of a resource by the final consumer such as the burning of gasoline in an automobile. This is not the case when the consumer uses electricity generated by oil-fired turbines; here, the oil is being consumed indirectly. Direct consumption of petroleum products was distributed with 79.3 percent having been used by the transportation sector,
### Total Energy Consumption

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Products</td>
<td>1240.41</td>
<td>74.11</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>311.66</td>
<td>18.61</td>
</tr>
<tr>
<td>Coal</td>
<td>120.20</td>
<td>7.18</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.64</td>
<td>0.04</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>1.00</td>
<td>0.06</td>
</tr>
</tbody>
</table>

### Energy Used for Electrical Generation & Transmission

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petro. Prod.</td>
<td>425.88</td>
<td>58.83</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>176.18</td>
<td>24.33</td>
</tr>
<tr>
<td>Coal</td>
<td>120.20</td>
<td>16.61</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.64</td>
<td>0.09</td>
</tr>
<tr>
<td>Hydroelec.</td>
<td>1.00</td>
<td>0.14</td>
</tr>
</tbody>
</table>

### Direct Use of Fuels

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petro. Prod.</td>
<td>814.49</td>
<td>85.74</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>135.47</td>
<td>14.26</td>
</tr>
</tbody>
</table>

### Waste

<table>
<thead>
<tr>
<th>Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Losses</td>
<td>8.22</td>
<td>0.5%</td>
</tr>
<tr>
<td>Total Energy</td>
<td>509</td>
<td>30.4%</td>
</tr>
</tbody>
</table>

### Residential & Commercial Use

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Products</td>
<td>78.91</td>
<td>29.92</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>32.93</td>
<td>12.48</td>
</tr>
<tr>
<td>Electricity</td>
<td>151.93</td>
<td>57.60</td>
</tr>
</tbody>
</table>

### Industrial Use

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Products</td>
<td>55.87</td>
<td>30.95</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>69.91</td>
<td>49.81</td>
</tr>
<tr>
<td>Electricity</td>
<td>34.72</td>
<td>19.24</td>
</tr>
</tbody>
</table>

### Transportation Use

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Products</td>
<td>646.24</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Other Uses

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Trillion BTU's</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Products</td>
<td>33.47</td>
<td>50.57</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>4.41</td>
<td>6.67</td>
</tr>
<tr>
<td>Electricity</td>
<td>28.29</td>
<td>42.76</td>
</tr>
</tbody>
</table>

---

Fig. 1. Flow diagram of energy consumption in Florida in 1972.
9.7 percent by the residential-commercial sector, and 6.9 percent by the industrial sector.

Energy consumption, as a function of fuel source, is shown in Table 4.

TABLE 4

ENERGY CONSUMED IN FLORIDA IN 1972
AS A FUNCTION OF FUEL TYPE

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>29.61</td>
</tr>
<tr>
<td>Residual Fuel</td>
<td>28.55</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>18.61</td>
</tr>
<tr>
<td>Middle Distillate</td>
<td>7.59</td>
</tr>
<tr>
<td>Coal</td>
<td>7.18</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>6.47</td>
</tr>
<tr>
<td>L.P. Gas</td>
<td>1.89</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td>0.06</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.04</td>
</tr>
</tbody>
</table>


Further reference to Figure 1 reveals that natural gas accounted for almost 19 percent of the total energy consumed in 1972. Of this, approximately 57 percent was utilized directly and 43 percent was used for the production of electricity. Of the natural gas used directly,
70.7 percent was used by the industrial sector, 25.9 percent by the residential-commercial sector, and 3.4 percent for other purposes.

Coal accounted for 7.2 percent of the total energy consumed in Florida; however, all of the coal was used to generate electricity.

Nuclear and hydroelectric sources contributed very little to the overall amount of energy supplied to the state in 1972. Only one nuclear plant, located at Turkey Point, and one hydroelectric facility, located at Jim Woodruff Dam on Lake Seminole, were in operation.

Figure 1, page 9, shows that each of the energy consuming sectors, with the exception of the transportation sector, used large amounts of electrical energy. In fact, 43.2 percent of all the energy consumed in Florida was used to generate electricity; and, 70.7 percent of all the electricity consumed was used by the residential-commercial sector with 26.3 percent going to the commercial side and 44.4 percent going to the residential side [1].

In many instances, electrical generating plants which utilize either natural gas or petroleum can substitute one of these fuels for the other. In 1972, better than 83 percent of the fuel used to generate electricity was
either petroleum or natural gas. This leads to the conclusion that both the total energy consumption and the electrical generating capacity of the state of Florida are dependent on these two fuels.
CHAPTER III

SOLAR ENERGY TECHNOLOGY OVERVIEW

As far back as 212 B.C., Archimedes, purportedly, collected the rays of the sun in optical concentrators and used the reflected energy to ignite the sails of the Roman warships arrayed against Greece. For thousands of years, solar energy has been used to distill and warm water and heat houses. Even today, entire islands in the Mediterranean and Caribbean use it to fulfill these same functions [3].

In medieval times, the sun's energy was used to distill perfume, recover salt from brine, and cook food. In more modern times, solar energy has been the subject of serious study and practical use for almost 100 years. At the World's Fair held in Paris in 1878, A. Mouchot demonstrated a solar water pump, which was driven with the mechanical power produced by gathering sunlight in a collector and using the reflected energy to produce steam. At Meadi, Egypt, in 1912, a solar plant was in operation which used cylindrical paraboloid reflectors to heat water to provide steam for a 100-horsepower piston engine [5]. Today, the energy of the sun, collected similarly, powers
the largest solar furnace ever built. The furnace, located at Odeillo in the French Pyrenees, is capable of producing temperatures as high as 3,300°C for the purpose of purifying precious metals and testing protective materials [6]. The most well-known application of solar energy has been its use, through conversion by solar cells, as a source of electrical power for this nation's space vehicles.

In the early 1900's, South Floridians used solar energy to heat their water in holding-tank-type systems, and, at the peak of the 1920's building boom, many homes were constructed with built-in solar tank systems. It has been estimated by various sources that as many as 60,000 solar water heaters are in use in South Florida today, nearly all of which were installed in the 1930's and 1940's before all-electric living became the vogue [7].

Today, a trip through any of the larger South Florida cities will turn up a negligible amount of residences utilizing solar heaters. Conversations with the Home Builders and Contractors Association and the Palm Beach County Area Planning Board indicate that 75 percent of all single-family residences in Florida have been constructed within the last 20 years and 46 percent within the last 10 years. Although there are no statistics available, conversations with residents of and travels through the
Florida Keys reveal that solar water heaters, once prevalent, have fallen into disuse and have been replaced with conventional systems.

A review of the numerous periodicals, technical reports, newspaper articles, and general literature available concerning solar energy revealed no large scale uses of or general applications of solar energy within the state of Florida.

The foremost reason for the decline of solar energy as a source of power was that it was being developed at a time in history when fossil fuel costs were, comparatively, very low. It could not compete in the energy market place and fell behind as both financial and research interests were channeled into the more technically and economically feasible areas. The convenience of readily available and relatively inexpensive electricity and bottled gas virtually eliminated solar power as a basic method of water heating.

Today, numerous experiments and studies have demonstrated that solar energy can be used for a multitude of diverse, commonplace tasks, such as hot water heating, space heating, air-conditioning, refrigeration, cooking, distillation, conversion to electricity, conversion to mechanical power, and metal purification. The technology is available to accomplish each of these items and has, in fact, been demonstrated at the University of Florida in its Solar Energy and Energy Conversion Laboratory [8]. Yet, there are
major economic and sociologic problems that must be overcome before the use of solar energy as a power source can become a viable proposition.

There are three significant reasons why the economics of solar energy technology is a problem. First, the solar energy reaching the surface of the earth is dilute in nature, having been dissipated somewhat by the atmosphere and, therefore, must be collected over a large area in order to supply enough for the more power-hungry projects. Solar energy passes through near-earth space at a rate of 130 thermal watts per square foot and arrives on the earth at a rate of 17 thermal watts per square foot when averaged over 24 hours. To produce the equivalent of the total predicted energy requirement for the U.S. in the year 2000 (175x10^{15} BTU per year) by converting the solar energy arriving on the ground at 10-percent efficiency would require about 124,000 square miles of land. This would result in an average daily output of approximately 1,140,000 kilowatt-hours per square mile [9]. This tends to make it expensive although it is free.

Second, solar energy is variable. On cloudy days, only 10 to 15 percent of the sun's normal radiation reaches the earth; there is less available in the winter than in the summer (330 to 1,130 BTU's per square foot per day in December versus 1,700 to 2,500 BTU's per square foot per day in June for the southeast); and none arrives at night [3].
To provide for periods of low intensity, the energy must be stored, and storing large amounts of energy, given the current state of the art, is both difficult and expensive.

Third, solar energy technology is new. As in any beginning field of research, the initial attempts are crude. It is only with time and further effort that the designs will become polished, both technically and economically. This is especially true in the case of current solar cooling technology.

Sociologically, market acceptance is the major problem that must be dealt with. Research by Dr. Karl W. Böer, Director of the Institute of Energy Conversion at the University of Delaware, indicates that such acceptance probably requires fulfilling at least five conditions [10]:

(A) Low first cost: less than 10 percent of the cost of the house before solar modification.
(B) Solar energy converted into compatible energy should cost no more than conventional energy.
(C) The solar energy system should have reliability similar to conventional systems.
(D) The solar energy system should perform at least as well as accepted conventional systems with regard to comfort control, etc.
(E) There should be visible incentives for at least one member of the builder/consumer chain without major disincentives for any other member.

An additional condition would be the requirement that the solar system be compatible with the building design. Psychologically, the aesthetics of the systems have a great effect on buyer potential.
Dr. Böer goes on to conclude that, in order to prevent the system from becoming too costly, the above conditions can be fulfilled, only if solar energy is used as supplemental rather than substitutional energy.

Within the state of Florida, the University of Florida has, for many years, been conducting research in the field of solar power. This work is now being carried on by Dr. Erich A. Farber as Director of the University's Solar Energy and Energy Conversion Laboratory and encompasses two areas: conversion of solar energy to alternate forms of energy and application of solar energy to new uses. The objective of the laboratory is to advance the state of the art and to provide the knowledge and the results for others to build on. At present, research is being conducted in the following areas:

1. Materials
2. Solar water heating
3. Space heating
4. Cooking and baking
5. Solar distillation
6. Refrigeration and air-conditioning
7. Solar furnace
8. Conversion to mechanical power
9. Hot air engines
10. Solar-heated sewage digestion
11. Conversion to electricity
The laboratory has looked into the older methods of converting solar energy into other forms of energy; it has studied the present state of the art; and, it has pioneered in many areas of solar energy utilization [8]. Its experiments have shown, to give the results of a very few, that glass makes the best collector and that the iron content in glass limits its transmission capabilities. Paint absorption characteristics are important; a green paint was found to be better than black in converting solar insolation into thermal energy [3]. Dr. Farber has shown that, in principle, solar energy can be used for any energy need now being filled by conventional fuels [11]. In the field of refrigeration and air-conditioning, Dr. Farber has developed a solar-operated ammonia, absorption refrigeration system using flat plate collectors without storage [12]. An in-depth treatment of the results of these projects is presented in Appendix A, which contains an enumeration of the papers published by Dr. Farber concerning the field of solar energy.

On the national level, much emphasis is being placed on the application of solar energy to residential-commercial heating and cooling. Reference to Chapter I, Table 3, page 7, shows that approximately 24.5 percent of all energy consumed in the United States is used for heating and cooling in this sector. The dilute and intermittent nature of solar energy has served to restrain its use in
many applications. One instance where these limitations are not so significant is in heating and cooling. Among the leading researchers in the field, there is general agreement that residential-commercial heating and cooling appear to be the most technically and economically feasible of the near-term uses of solar energy. A NASA report [13] concerning the development of a solar-powered residential heating and cooling system says:

... The first major application of solar energy will be to heat and cool buildings since this application will require the fewest technological advances and the least expenditures of time and money.

Another report [3] on the development of solar energy prepared for NASA by Auburn University contains the following statement:

... One case where dilution is not as significant a deterrent is in the heating and cooling of buildings. ... Additional advantages of solar energy for heating and cooling in buildings are its widespread availability and easy conversion to thermal form. ... Therefore, it is logical to utilize it directly in the heating and cooling of buildings and avoid losses that would occur by conversion to some other form.

There are approximately 20 to 30 experimental solar heated structures working across the U.S. Various combinations of collector types, heat storage techniques, heat transfer media, and auxiliary energy supplies have been tested. Some of these buildings were laboratories and some were also designed as residences. A brief summary of some of those tested is contained in Appendix B. It is noteworthy
that none of these systems has been able to supply 100 percent of the heating or cooling needs.

The University of Florida has a solar house as a part of its Solar Energy Laboratory and has graduate students living in it as part of a controlled test under actual conditions. Eventually it will derive all of its energy from the sun. Hot water is generated using a 4-by-12-foot solar converter with the water stored in a 100-gallon tank. Heat for the house is supplied by a 270-square-foot (at about $2.50 per square foot) solar panel and a 3,000-gallon storage tank. Cooking will be done by the addition of a solar-heated oil unit. The house has a solar-heated swimming pool, a liquid waste solar recycling system, and a small solar energy-to-electricity conversion system which powers a television set, a radio, the house lights, and the other small appliances. The laboratory is also testing a solar-electric car [14].

Most of the major research in the field of solar energy is being funded by the government through the Research Applied to National Needs (RANN) program of the National Science Foundation. RANN pairs the industrial and academic communities into teams which attempt to develop technology that will achieve significant contributions to the United States energy supply by the 1980's. The solar energy portion of this program is a two-part project which deals with the heating and cooling of buildings and with the
generation of electricity. The heating and cooling project is examining solar systems which will have wide application and be cost competitive with existing systems. The generation of the electricity phase is working with various methods of converting solar energy into electricity [15].

The heating and cooling program is divided into three segments. In the first segment, General Electric and the University of Pennsylvania, TRW and Arizona State University, and Westinghouse in conjunction with Colorado State University and Carnegie-Mellon University have formed industrial-academic teams to explore the feasibility of using solar energy to heat, cool, and provide hot water for buildings using state-of-the-art technology. The second, and following, segment of the program will cover preliminary system design and subsystem research, while the final segment encompasses system testing and proof-of-concept experiments [16].

The solar energy-to-electricity program is working mainly in two areas. In the area of photovoltaic energy, there are eight industrial academic teams working with materials, devices, and systems studies trying to develop low-cost, long-lived solar cell arrays for terrestrial applications. Additional information is presented in Appendix C. Here, the main objective is to reduce the cost of solar cells from $50 per peak-watt to 50¢ per peak-watt, two orders of magnitude, in order to produce photovoltaic
electricity which will be comparable price-wise with power station electricity [15].

In the area of solar thermal energy, industrial-academic teams are working to produce supplemental power for the present central power systems by converting solar energy into heat and steam for the production of conventional shaft work. Appendix C contains more detail. This is done by developing selective surfaces, surfaces that do not re-emit absorbed energy as heat. The heat trapped by the surface is then transferred to some medium such as a low-melting-point eutectic for storage where it can be extracted, when needed, to generate steam to drive turbogenerators [15].

Florida Technological University, in conjunction with Chrysler Corporation, is working in the residential heating and cooling portion of the program on a project to improve the first-generation design of an absorption air-conditioning system.

The object of this effort is to evaluate and define the performance conditions and hardware functional requirements for a second generation system that operates with hot water in the range of 170-185°F, has the cooling capability compatible with individual homes and building complexes (approximately 3-5 tons), and is optimized in terms of equipment cost and electrical power requirements [17].
CHAPTER IV

SOLAR ENERGY FOR HEATING AND COOLING

The most recent and most thorough studies of total system costs have been performed by Richard Tybout and George Löf. Using an elaborate computer model, they determined the least cost design for a typical solar house in eight cities across the United States. The climates of these cities represent the temperate and semi-tropical regions of the world [4].

The studies were based on weather bureau observations and existing engineering knowledge of solar designs and simulates solar operation over extended periods. Solar costs were based on a discount rate of 6 percent with sinking fund depreciation over an expected life of 20 years. Capital costs were based on the then current price of solar collectors of about $4 per square foot plus the costs of ancillary equipment (motors, pumps, controls, etc.) and on an anticipated near-term (mass production) collector price of $2 per square foot [4]. Their complete rationale may be found in Reference [4].

Table 5 summarizes the findings of Tybout and Löf using solar energy to provide both space heat and hot water
to middle income housing (requires 15,000 BTU/DD for approximately 1,000 square feet of floor space) and upper-middle income housing (requires 25,000 BTU/DD for approximately 1,700 square feet of floor space) optimizing on the basis of least cost.

**TABLE 5**

**LEAST COST SOLAR HEAT**

<table>
<thead>
<tr>
<th>Location</th>
<th>Collector Area (ft²)</th>
<th>Solar Heat (%)</th>
<th>15,000 BTU/DD Cost ($/10⁶ BTU)</th>
<th>25,000 BTU/DD Cost ($/10⁶ BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Maria</td>
<td>261</td>
<td>75</td>
<td>1.35</td>
<td>1.10</td>
</tr>
<tr>
<td>Albuquerque</td>
<td>261</td>
<td>60</td>
<td>1.70</td>
<td>1.60</td>
</tr>
<tr>
<td>Phoenix</td>
<td>208</td>
<td>72</td>
<td>2.55</td>
<td>2.05</td>
</tr>
<tr>
<td>Omaha</td>
<td>521</td>
<td>47</td>
<td>2.65</td>
<td>2.45</td>
</tr>
<tr>
<td>Boston</td>
<td>347</td>
<td>50</td>
<td>2.70</td>
<td>2.50</td>
</tr>
<tr>
<td>Charleston</td>
<td>208</td>
<td>55</td>
<td>3.15</td>
<td>2.55</td>
</tr>
<tr>
<td>Seattle-Tacoma</td>
<td>521</td>
<td>45</td>
<td>2.85</td>
<td>2.60</td>
</tr>
<tr>
<td>Miami</td>
<td>52</td>
<td>70</td>
<td>5.85</td>
<td>4.05</td>
</tr>
</tbody>
</table>


The solar heat column shows the percentage of heat supplied by the solar system. Practically speaking, 100 percent of the heat cannot be supplied by the solar
components. This is because the costs of solar heating are almost all in fixed capital investment and because additional capacity beyond the least cost levels would be used with ever-decreasing frequency. In other words, the ratio of system cost per BTU received starts to increase exponentially.

The costs presented in Table 5 are actual system costs that were valid for the period when the study was begun. Today, these costs would change somewhat because of inflation, production techniques, etc. However, the comparisons are still valid. The costs of the 15,000 BTU/DD home are higher than those of the 25,000 BTU/DD home because most of the costs (fixed capital investment) are common to both. The main difference between the two systems is the additional collector area required by the larger home. This does not increase the cost per BTU because collector costs are small relative to the fixed costs.

The high cost for solar heating in the Miami area might, at first, seem puzzling. With so much sun, how can it be expensive? But, the authors conclude that Miami is a poor site for solar house heating as it does not have enough demand to use the solar equipment effectively even though a high percentage of its small annual demand can be satisfied by solar energy. In other words, there are just not enough cold days to justify the system [4].
Alternatively, the authors conclude that [4]:

... On the same basis as used for space heat systems (6% interest, sinking fund depreciation) annual equivalent costs are 66 to 92¢/ft², respectively, which gives a hot water cost of $1.97 to $2.84 per million BTU. The advantages of installing a simpler hot water-only system rather than a space heat-hot water combination are obvious for Miami. Indeed, costs of solar heated water in Florida are within the same range as conventional fuel costs, as will be seen from Table 2 [Table 7 in this report]. In practical applications, supplementary heat is required for hot water, as for space heat, if 100 percent capability is desired.

The results of further studies on combined solar heating and cooling systems optimized on the basis of least cost are presented in Tables 6 and 7. The solar collectors can now be used for both heating and cooling with corresponding improvements in the load factor and lower unit output costs of the collectors. Comparison of Tables 5 and 6 shows that the cost per million BTU decreases significantly for Miami using a system that now has a high-load factor. Now there is enough combined heating and cooling demand to reduce system costs to an extent that the solar system becomes viable.

Table 7 presents an informative comparison of costs between solar energy and conventional fuels. On the solar energy side, the heating costs presented are those using the combined system to heat only. Similarly, the cooling costs are those using the combined system to cool only. Note that, in a wide variety of climatic conditions, using the solar system is less expensive than using electricity and is
## TABLE 6
LEAST COST SOLAR HEATING AND COOLING
(25,000 BTU/DD House)

<table>
<thead>
<tr>
<th>Location</th>
<th>Collector Area (ft²)</th>
<th>Combined Heating and Cooling (% Solar)</th>
<th>Cost ($/10^6 BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque</td>
<td>577</td>
<td>63</td>
<td>1.73</td>
</tr>
<tr>
<td>Miami</td>
<td>1,150</td>
<td>60</td>
<td>2.13</td>
</tr>
<tr>
<td>Charleston</td>
<td>1,150</td>
<td>68</td>
<td>2.47</td>
</tr>
<tr>
<td>Phoenix</td>
<td>1,150</td>
<td>33</td>
<td>1.71</td>
</tr>
<tr>
<td>Omaha</td>
<td>1,150</td>
<td>59</td>
<td>2.48</td>
</tr>
<tr>
<td>Boston</td>
<td>1,150</td>
<td>65</td>
<td>3.07</td>
</tr>
<tr>
<td>Santa Maria</td>
<td>289</td>
<td>52</td>
<td>2.45</td>
</tr>
<tr>
<td>Seattle-Tacoma</td>
<td>577</td>
<td>43</td>
<td>3.79</td>
</tr>
</tbody>
</table>

### TABLE 7

**COMPARISON OF SOLAR HEATING AND COOLING COSTS WITH ALTERNATE FUELS ($/10^6 BTU)**

<table>
<thead>
<tr>
<th>Location</th>
<th>Gas</th>
<th>Oil</th>
<th>Electricity</th>
<th>Heating</th>
<th>Cooling</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque</td>
<td>0.89</td>
<td>2.07</td>
<td>4.62</td>
<td>2.03</td>
<td>3.29</td>
<td>1.73</td>
</tr>
<tr>
<td>Miami</td>
<td>2.81</td>
<td>1.73</td>
<td>4.90</td>
<td></td>
<td>2.26</td>
<td>2.13</td>
</tr>
<tr>
<td>Charleston</td>
<td>0.96</td>
<td>1.55</td>
<td>4.22</td>
<td>3.34</td>
<td>3.49</td>
<td>2.47</td>
</tr>
<tr>
<td>Phoenix</td>
<td>0.79</td>
<td>1.60</td>
<td>4.25</td>
<td>2.87</td>
<td>2.05</td>
<td>1.71</td>
</tr>
<tr>
<td>Omaha</td>
<td>1.05</td>
<td>1.32</td>
<td>3.24</td>
<td>2.93</td>
<td>5.41</td>
<td>2.48</td>
</tr>
<tr>
<td>Boston</td>
<td>1.73</td>
<td>1.76</td>
<td>5.25</td>
<td>3.02</td>
<td>8.72</td>
<td>3.07</td>
</tr>
<tr>
<td>Santa Maria</td>
<td>1.42</td>
<td>1.62</td>
<td>4.36</td>
<td>1.58</td>
<td>1.46</td>
<td>2.45</td>
</tr>
<tr>
<td>Seattle-Tacoma</td>
<td>1.83</td>
<td>2.00</td>
<td>2.31</td>
<td>3.14</td>
<td>1.95</td>
<td>3.79</td>
</tr>
</tbody>
</table>

nearly competitive with gas and oil. In every case, with the exception of Seattle with its unusually low electric power rates, solar energy is cheaper than electricity and approaches the cost of gas and oil. In Miami, the solar system costs are 57 percent less than electricity, 25 percent less than gas, and only 23 percent more than oil.

In summary, despite the changing prices seen today, which will modify the actual costs, the inescapable conclusion is that solar heating and solar cooling have definite potential for use in Florida.

These results have been somewhat confirmed by the Westinghouse-Colorado State University-Carnegie-Mellon University report on the feasibility of using solar energy to heat and cool, previously mentioned in Chapter III. The report concludes that [18]:

... Solar-assisted space heating and water heating for single-family homes can be cost competitive in the 1975-1980 period in some regions of California where little space heating is required. But, in most regions of the country... solar heating and cooling systems can become cost competitive in the 1985-1990 time period as fuel prices escalate and solar equipment prices fall with quantity production.

There is currently a gap between the near-term costs for solar systems and the additional cost that consumers would be willing to pay. Government programs and incentives will be necessary to close the gap.

Installing solar systems in existing single-family homes will not be economically feasible on a significant scale. To be economically and aesthetically attractive, single-family homes should be specifically designed for a solar system. Cost advantages may be achieved, however, by retrofitting solar systems into larger multifamily and commercial buildings.
CHAPTER V

SOLAR CONVERSION INDUSTRY

Despite the ready availability of solar energy in the state of Florida, there are relatively few solar-related industries. This is due to the reasons enumerated in Chapter III. Solar water heating is the only program which is technically and economically practical at this time. Other programs, such as solar cooling, though feasible, still have unresolved problems to be considered. The NSF/NASA Solar Energy Panel concludes that [11]:

Before solar energy becomes a major source of clean energy for our nation, it will require the involvement of industrial ingenuity and productive know-how to produce economic hardware and services. Some of the difficulties in achieving industry participation are: (1) most companies are looking for short term projects for their new enterprises with return on their investments in two or three years; (2) long range projects present great risk, and investment capital is very scarce unless there is a high probability of return in a major line in their business; and (3) companies will undergo major change only under crisis (they will take chances but cannot take failure).

There is no real solar industry in Florida. Appendix D contains a list of those firms in Florida known to be working with solar-powered systems. Conversations with these firms revealed that there is no defined price structure; a hodgepodge of systems is available. The
following is a summary of what the firms contacted offered in the way of solar water heaters.

W. R. Robbins and Sons Roof offered several system sizes. For a 3,000-watt, 250-volt, 80-gallon system with a thermostat and a 4- by 12-foot collector, uninstalled, the price was $625. For the same system with a 100-gallon tank, the price was $697.

Youngblood Company, Inc., quoted $1,500 to $1,800 for an installed system capable of supporting the hot water and space heating needs of a three-bedroom house with four people.

MacDonald Window Sales and Service said their hot water systems ranged from $300 to $900 with a collector price of $6.50 per square foot. Additionally, they offered a total system for the average Florida three-bedroom home; for $800 to $1,000 installed, they will supply a system which provides hot water, space heating, and air-conditioning for the average Florida residence.

Pyramid Plumbing sells 3- by 8-foot collector panels for $399 or approximately $17 per square foot, uninstalled.

Solar Power Corporation quoted $395 for a 2- by 8-foot copper collecting panel, a fractional H.P. pump, and some ancillary electrical equipment and check valves, uninstalled. The same system with an aluminum collector panel sells for $295.
From the above, it can be seen that, because there are so few firms offering solar systems, there is a vast discrepancy in prices. There were no data available about the efficiencies of the various schemes or their designs.

The information obtained from firms dealing in solar-energy-related products has been sparse. Only 29 percent of the inquiries made received a reply. In several of the replies, it was implied that most companies would not be too cooperative because of the possibility of leaking information vital to their competitive position.

Information was received from two foreign firms which make and install solar hot water systems.

From correspondence with Amcor Export Company, Ltd., Tel-Aviv, Israel, it was learned that a system with a 32-gallon storage tank with auxiliary 1,500-watt, 220-volt heater and two collector panels sells for $275. No quotation was made about collector costs. However, quotations from Sol-Therm Corporation in New York, which imports the Amcor systems from Israel to the U.S., read $595 for the standard domestic water heater described above with $195 for additional collector panels. This works out to approximately $12 per square foot as the cost of the collector.

Correspondence with Beasley Industries Pty., Limited in Australia confirms that for the average Australian home (in a generally colder climate than Florida) a solar hot
water system costs from $300 to $365 more than the normal electric hot water system with collector costs running about $8 per square foot.

No information was available concerning Japanese or Russian solar equipment.
CHAPTER VI

SOLAR ENERGY POTENTIAL

In the future, using solar energy as a source of power could do much to preserve fossil fuels for other uses, such as medicines and plastics. Solar energy must be developed to help fill the increased demand for energy. This is necessary to prevent fossil fuels from becoming scarce causing a serious escalation in their prices. Such escalations would lead to potentially serious balance-of-payments deficits and would fuel worldwide inflation through the rise in prices of associated goods.

Technology has demonstrated that solar energy can be converted into thermal energy, electrical energy, and mechanical energy. To replace the energy which would otherwise have been obtained from fossil fuels, the available solar energy should be used. In this respect, Florida enjoys the advantage of having a subtropical climate in which approximately 60 percent of the winter days are clear. The state as a whole has clear or partly cloudy days about 65 percent of the year and has an average temperature of about $59^\circ F$ ($15^\circ C$) in January and $81^\circ F$ ($27^\circ C$) in July with an average minimum winter temperature throughout its
southern half of about 50°F (10°C) [19]. Additionally, Florida receives average daily solar radiation of 1,650 BTU per day per square foot which is, with the exception of the southwest, higher than any other area in the United States which itself averages 1,400 BTU per day per square foot [20].

Solar energy is able to supply several solutions to the important problems concerning environmental impact, but it has its own potential problems. Today’s power production presents society with inherent problems, such as the waste of both energy and material and the resulting pollution, none of which are directly present with the use of solar energy. But, the environmental question is much more sophisticated than this. Depending on the final methods developed to utilize this energy, large investments of natural resources, such as copper, aluminum, transport fluids, storage materials, etc., would be required. Because of the low intensity of this radiation, large land areas might be needed for its collection.

Solar and nuclear energy are thought to be the highest potential long-range energy resources. However, the future of nuclear energy appears to be bogged down with serious problems relating to plant operation and the release of radioactivity. Such serious problems do not appear to be present with the use of solar energy.

Regardless of the methods used to supplement fossil fuels in the future, before they are undertaken with any
seriousness, it is imperative that environmental impact studies be made to weigh objectively the benefits derived against their costs.

The potential of solar power as a substitute source of energy can be determined as follows. Set as a goal the obtaining of the maximum use of this energy by the year 2020, utilizing existing thermal energy techniques in residential-commercial heating and cooling. That is, assume that the systems are installed without regard to cost using the current technology.

As a guideline to future energy consumption, the Brookhaven (AET-8) Projection which was issued in 1972 by the Brookhaven National Laboratory will be used. This information is presented in Table 8. This projection is based on several main assumptions [3, 21] concerning factors which affect energy usage:

1. The use of air-conditioning will continue to increase for about twenty years at its present 15.6 percent residential and 8.6 percent commercial growth rates (based on 1960-1968 rates) and then level off.

2. The energy required to heat and cool buildings will decrease slowly due to design improvements. At present, energy for heating and cooling comprises 24.4 percent of total energy consumption. This is expected to rise to 25.0 percent by 1990 and then fall off to 18.0 percent by 2020.

3. The population growth rate will remain at its present level.

4. Other energy uses will probably grow more quickly than heating and cooling. This is evidenced by the expected decline of the amount of energy for heating and cooling with respect to total energy consumption.
**TABLE 8**

**PROJECTED NATIONAL ENERGY CONSUMPTION**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Energy Consumption (Quads)*</th>
<th>Energy for Heating and Cooling Amount (Quads)</th>
<th>Percent of Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>60.5</td>
<td>13.25</td>
<td>24.4</td>
</tr>
<tr>
<td>1980</td>
<td>88.0</td>
<td>22.00</td>
<td>25.0</td>
</tr>
<tr>
<td>1990</td>
<td>127.0</td>
<td>31.80</td>
<td>25.0</td>
</tr>
<tr>
<td>2000</td>
<td>175.0</td>
<td>38.50</td>
<td>22.0</td>
</tr>
<tr>
<td>2010</td>
<td>230.0</td>
<td>46.00</td>
<td>20.0</td>
</tr>
<tr>
<td>2020</td>
<td>300.0</td>
<td>54.00</td>
<td>18.0</td>
</tr>
</tbody>
</table>


*One quad equals $10^{15}$ BTU.*
Further assumptions made in this report that will aid in determining solar energy potential are:

1. There will be a major commitment of R&D money during the next 15 years, increasing as the true magnitude of the energy crisis becomes apparent.

2. Solar energy use, on relatively large scale terms, will begin in 1980 as a consequence of the R&D studies and inertia within the construction industry.

3. Solar heating and cooling techniques will be used only on new construction since retro-fitting will be both difficult and expensive.

4. Solar heating and cooling will provide 75 percent of the total energy required to heat and cool with the remainder supplied by a conventional system. Present systems, as indicated in Table 6, page 28, could supply approximately 55 percent of the total needed. Thus, about a one-third increase is expected in system output due to technological advances.

5. No more than 75 percent of new construction will utilize solar energy because of obstructions, climate, etc.; and this will occur as shown in Table 9. This figure is a probable upper limit and would not be reached except in extraordinary circumstances.
TABLE 9
SOLAR ENERGY AND NEW CONSTRUCTION

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1981-1990</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>1991-2000</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>2001-2010</td>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td>2011-2020</td>
<td>75</td>
<td>27</td>
</tr>
</tbody>
</table>


By using the previous assumptions together with the information contained in Tables 8 and 9, a projection of the amount of solar energy which could be substituted for the energy derived from fossil fuels is shown in Table 10.

Table 10 indicates that it will be at least 40 years before solar energy will make an impact as an energy source if it is confined to heating and cooling using current or similar thermal energy techniques.

Table 10 also demonstrates that solar energy cannot be restricted to the heating and cooling needs of new residential-commercial construction. The 9.3 quads of energy predicted to be developed by solar energy in 2020 is but 56 percent of that which was expected to have been needed in 1974 (Table 8) for heating and cooling. The
amount of energy expected to be produced is significant by today's standards (Table 4, page 10, shows that hydroelectric and nuclear sources supplied only 0.1 percent of Florida's energy in 1972); but, by the standards of the year 2020, it is not what was hoped for.

### TABLE 10

**FUTURE SOLAR ENERGY CONSUMPTION**

<table>
<thead>
<tr>
<th>Year</th>
<th>Solar Energy Consumption (Quads)</th>
<th>Total Energy Replaced (%)</th>
<th>Heating and Cooling Energy Replaced (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1990</td>
<td>0.73</td>
<td>0.58</td>
<td>2.31</td>
</tr>
<tr>
<td>2000</td>
<td>1.99</td>
<td>1.14</td>
<td>5.17</td>
</tr>
<tr>
<td>2010</td>
<td>4.80</td>
<td>2.09</td>
<td>10.44</td>
</tr>
<tr>
<td>2020</td>
<td>9.30</td>
<td>3.10</td>
<td>17.23</td>
</tr>
</tbody>
</table>

*See Appendix E for calculation.

If, starting in 1980, the new construction had all of its heating and cooling needs supplied by solar energy, then it would supply only 4 percent of the total energy or 23 percent of the heating and cooling energy needed in 2020. If, in addition, all of the new construction were to use it, then the above figures would rise to 11 percent and 59 percent, respectively.
For solar energy to make a significant contribution in the energy market place, it must be able to be converted to a useful form by existing structures and/or be used by other energy consuming areas.

It is the writer's belief that significant inroads in energy production utilizing solar power will occur only when this energy is converted to electricity. Reference to Figure 1, page 9, shows that 43.2 percent of all the energy consumed in Florida was used to produce electricity.

Solar energy could have a sizable effect on power generation if it were to replace the fossil fuels used to produce electricity. If this line of reasoning is followed further, it is possible to conceive that in the future a large portion of all the gasoline used for transportation could be eliminated by using electric cars. In Table 2, page 6, it was seen that gasoline comprised 28.8 percent of the energy consumed in Florida in 1972. Furthermore, ideally all of the petroleum products and natural gas used in the residential-commercial sector could be substituted for using electricity. This amounts to 6.7 percent of the energy consumed in 1972. Therefore, it is possible that up to 78.7 percent of the energy consumed within Florida could be the product of electricity generated utilizing solar energy.
In the previous chapters, the following statements have been made and the following conclusions have been drawn concerning energy in the state of Florida:

1. Residential heating and cooling consume almost 25 percent of the energy utilized in the United States.

2. Fossil fuels supply approximately 99.9 percent of all the energy consumed in Florida.

3. Because fossil fuel resources are limited, alternate sources of energy must be developed.

4. Solar energy technology has demonstrated the capacity to heat, cool, and produce electricity.

5. In Florida, solar hot water heaters can be installed and run economically, but there are problems which prevent its use at present for air-conditioning and space heating.

6. There is no substantial solar industry in Florida.
7. Solar energy thermal technology will not make an inroad as a significant source of power until the twenty-first century, 25 years hence.

8. Solar energy must be converted to electricity in order to be able to make a significant impact as a source of energy in the next two decades.

Some of the steps which could be taken to help solve the energy problems both of Florida and of the United States are as follows:

1. The federal government must take the lead and adopt a national energy policy directed toward three major areas: the supply of energy, the demand for energy, and the conservation of energy.

2. To increase the supply of energy, the government needs to increase the funds for energy R&D in all areas. This is to prevent a reliance on any one method, such as nuclear energy, should that method prove technically or environmentally unsound in the future. In the aftermath, it may be that solar energy will be the only dependable source of energy. Also, other sources may be developed which could supply a small, but significant, portion of our total energy resources.
3. On both the national and state levels, in order to utilize the existing solar energy technology, incentives must be provided [1]:

... for persons wishing to construct, produce, install, or purchase solar energy systems. In order to foster an embryonic industry, to save public funds through lower energy operating costs, and to help develop a reliable product for consumers, state building construction must consider solar water heating, space heating, and air-conditioning. The use of solar equipment must be considered in design alternatives which include evaluation of life cycle building costs.

Furthermore, to encourage persons to invest in solar energy systems production and installation, tax incentives in the form of corporate income tax credits should be provided. In order to encourage persons to purchase solar energy systems products, tax incentives in the form of Sales Tax exemptions for such products should be provided.

4. To regulate the demand for energy, population growth and per capita consumption must be controlled. The consumption of energy is, in part, a function of population expansion. This increase must be controlled if the present standard of living is to be maintained. At best, the United States should continue to aim for the zero population growth it is so near to attaining. To control per capita consumption, both the national and state governments must launch educational programs to increase public awareness of the problem and avoid unnecessary waste. Perhaps, energy rates could be structured such that costs rise after a certain level of consumption has occurred. Other suggestions include the encouragement of intercity and intracity public
transportation, the regulation of the price of imported oil, the encouragement, by national legislation, of improved fuel economy in automobiles, and the passing of state and national legislation requiring all major appliances to disclose their efficiencies and expected annual costs of operation.

5. Conservation of energy is an area where immediate steps can be taken. The federal and state governments in conjunction with industry must examine ways to improve the efficiency of existing designs and encourage the input of solar concepts where possible. The three areas of consumption where such a program would have maximum effect is in the designing of buildings, the revision of industrial processes, and the improvement of transportation efficiencies. By proper planning, large savings in energy could accrue in these three areas. An Office of Emergency Preparedness Report estimates that the potential for energy conservation may be as great as 16 percent of total energy consumption by 1980.
APPENDIX A

PUBLICATIONS OF DR. ERICH A. FARBER


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1957.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1958.


These publications are listed as received from Dr. Farber.

47

"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1959.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1960.


"Tests Prove Feasibility of Solar Air Conditioning"
"M. Eisenstadt, F. Flanigan, E. A. Farber, Florida Engineering and Industrial Experiment Station, Vol. 32, No. 11, November 1960.

"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1961.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1962.


"A Brief History of U. S. Weather Bureau" (3p).
"Selective Absorption of Energy by Painted Metal Surfaces When Irradiated by Artificial Sources" (3p).
"Theoretical Effective Reflectivities of Drapery Materials as a Function of Geometric Configuration" (2 p).
"The University of Florida - ASHRAE Solar Calorimeter" (2p).
"A New Method of Calculating Heat Gain Through Sun-Lit Glass (2p).
"Experimental Cooling" (3p).
"University of Florida Air-Conditioning Unit" (4p).
"Crystals of High Temperature Materials Produced in the Solar Furnace" (3p).
"A Double Compound Thermal Image Furnace for Continuous Operation" (2p).
"Photosynthesis" (3p).
"Performance of Single Effect Solar Stills" (2p).
"Multiple Effect Humidity Process" (2p).
"Basin Type Solar Stills" (2p).
"The Inclined Tray 'Sunagua' Solar Still" (lp).


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1964.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1965.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1966.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1968.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1969.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1970.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1971.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1972.


"Solar Energy Conversion Research and Development at the University of Florida Solar Energy and Energy Conversion Laboratory" Dr. E. A. Farber, Reprint from the article in Buildings System Design, June 1972.


"Solar Radiation Data" E. A. Farber, Climatological Data, National Summary, Published monthly by the U. S. Weather Bureau, Department of Commerce, January through December 1973.


APPENDIX B

STRUCTURES UTILIZING SOLAR ENERGY

This appendix contains a brief summary of a variety of structures utilizing various solar energy concepts.

A series of experiments devised at the Massachusetts Institute of Technology led to the successive development of four solar-heated structures, the last of which was located at Lexington, Massachusetts. The building was a carefully engineered and instrumented system using solar water heaters and water storage. The solar heating system was designed to carry about two-thirds of the total winter heating loads [22].

G. O. G. Löf designed air heating systems using pebble bed exchangers for energy storage. He has studied the characteristics of these storage systems and designed and built near Denver, Colorado, a residence in which he has lived for the past 15 years using these concepts [22].

Another approach to solar heating has been to use an uncovered, nearly horizontal, water heating solar collector as the roof of a building. The uncovered collector serves as a radiator to reject heat to the clear night sky, providing some cooling in appropriate climates. R. W. Bliss
designed and built such a system in Tucson, Arizona, using a heat pump to augment the gains from the collector during the heating season and the cooling capacity of the radiator during the air-conditioning season [22].

An experimental house in Delaware, Maryland, uses a combination of cadmium sulphide photovoltaic arrays and flat plate collectors. The electric power generated by the solar arrays is passed to an electrochemical storage system to be held in reserve until need or used directly in the house. Air is circulated behind the solar collectors, and the latent heat is stored in tubes containing fused salts which have melting points of about 10°C (50°F), 24°C (75°F), and 50°C (120°F). During the heating season, air from the interior is circulated through the 50°C salt and extracts the heat of fusion from the salt as it freezes. During the cooling season, the 50°C salt can be used with a heat pump to freeze the 10°C salt and air-condition the residence [23].

In Phoenix, Arizona, an air-conditioning system using solar radiation as a heat source and the atmosphere as a heat sink has been tested for an entire year. A movable insulated roof permits water ponds in thermal contact with a metallic ceiling, to absorb and retain solar heat in the winter and dissipate summer heat to the night sky. With ambient temperatures ranging from freezing to 115°F, the
system maintained room temperature between 68°F and 82°F for an entire year without supplementary heating or cooling [24].

A residence in Washington, D.C., has 83 percent of its winter heat supplied by solar collectors on the roof. Inside them, water flows over corrugated aluminum roofing absorbing the heat from the sun and flowing through a system of pipes that takes it through the heating units in the house, or, when it is not needed, into a 1,600-gallon insulated storage tank [25].

An office building in Lincoln, Massachusetts, is expected to have a heating load range of from 260 to 360 BTU per hour, a cooling load range of from 17 to 26 tons of air-conditioning, and hot water demands of up to 100 gallons per day. To supply these needs, the building will use a standard two-pane absorber flat-plate collector of 3,500 square feet with water as the storage medium and a 7,500-gallon hot/cold storage tank (insulated). The air-conditioner is an ARKLA Li Br 15-ton absorption unit. The air-conditioner is expected to supply a significant portion (unknown) of the cooling load and is backed up by a 7.5-ton electrical auxiliary unit. The solar heater has two-day storage for the winter, is backed up by a 220,000-BTU per hour furnace, and is expected to supply 60 to 75 percent of the annual heating load. All hot water will be supplied from the solar unit [3].
APPENDIX C

NSF/RANN PROGRAM ON ENERGY

In the field of photovoltaics, the major activity concentrates around the use of silicon and cadmium sulphide as the prime materials for solar cell arrays. The objective is to reduce the size of the wafer by growing thin ribbons of silicon, or alternatively, thin films of the material, either of which must be capable of being mass produced. Another possibility is the use of concentrators to mass produce silicon materials for solar cells. Cadmium sulphide is by itself a thin material and has the potential to become a very low cost material if mass production can be achieved [15].

Texas Instruments and Southern Methodist University are teamed to investigate the fabrication of polycrystalline silicon thin film cells on a continuous basis. Tyco Laboratories and Harvard University are investigating the production of continuous ribbons of single crystal silicon for solar cells. The University of Delaware is trying to improve CdS/CU_2S solar cells. Boston College is studying low cost polycrystalline silicon photovoltaic cells for large solar power systems [15].
In the field of solar thermal energy, the University of Minnesota and Honeywell are performing system studies and research on parabolic trough solar energy collectors. The University of Houston and McDonnell Douglas are assessing the economic feasibility of a system in which radiation from the sun is reflected from a large array of mirrors to an absorber unit mounted in a central tower that contains power generators. The University of Arizona is investigating the conversion of solar energy into thermal radiation through the use of radiation-selective coatings. The thermal energy produced is then used to generate bulk electrical power [15].
### APPENDIX D

#### SOLAR INDUSTRY IN FLORIDA

The following is a compendium of firms which manufacture, are researching, and/or installing solar devices in Florida.

<table>
<thead>
<tr>
<th>Firm</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beutel's Solar Heater, Inc.</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>1527 North Miami Avenue</td>
<td></td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Robbins W. R. &amp; Son Roof</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>1401 N.W. 20th Street</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Solar Water Heater</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>9951 S.W. 38th Street</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Youngblood Company, Inc.</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>1085 N.W. 36th Street</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>McDonald Window Sales &amp; Service</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>3003 N.E. 19th Drive</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Gainesville, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Pyramid Plumbing, Inc.</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>1708 S. Congress</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>West Palm Beach, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Wilcon Corporation</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Ocala, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Solar Tech</td>
<td>Make and install solar water heaters</td>
</tr>
<tr>
<td>Lakeland, Florida</td>
<td>Make and install solar water heaters</td>
</tr>
</tbody>
</table>
Firm

CSI Solar Systems Division
North Tamiami Trail
North Fort Myers, Florida

Galaxy Swimming Pools
304 Nesbit Street
Punta Gorda, Florida

Roy M. Albert, Inc.
P. O. Box 10981
St. Petersburg, Florida

Solar Structures, Inc.
119 Arctuas Avenue
Clearwater, Florida

Solar Power Corporation
Route 4
Port Richey, Florida

Wilcox Corporation
Pinellas Park, Florida

Vantage Solar Corporation
P. O. Box 1773
Winter Park, Florida

S. S. Gasket Company
4939 Distribution Drive
Tampa, Florida

Area

Make and install solar water heaters

Make and install solar water heaters

Make and install solar water heaters

Solar water heaters and cooling

Solar water heaters and cooling

Solar air-conditioning and heating refrigeration

Solar air-conditioning and heating refrigeration

Manufactures parts for firms in the solar energy field
APPENDIX E

CALCULATIONS

The energy for heating and cooling in 1990 minus the energy for heating and cooling in 1980 (Table 8, page 38) gives the growth of energy between 1980 and 1990:

\[
\begin{array}{c}
31.80 \text{ quads} \\
-22.00 \text{ quads} \\
\hline
9.80 \text{ quads}
\end{array}
\]

This energy growth is due to new construction.

Ten percent of the new construction uses solar energy. Therefore, 9.80 times 0.10 (Table 9, page 40) or 0.980 quads of solar energy would be used if solar energy supplied 100 percent of the heating and cooling needs.

But, solar energy supplies only 75 percent of the energy needed for heating and cooling; therefore, 0.980 times 0.75 or 0.735 quads of energy could be supplied by solar energy.

Thus, 0.735/31.8 or 2.31 percent of the heating and cooling needs can be supplied by solar energy. And, 0.735/127 or 0.58 percent of total energy consumption can be supplied by solar energy.
For the period from 1990 to 2000, the type calculation is the same as above except that the energy due to solar power from the previous decade (0.735 quads) must be added to the solar energy total.

The energy for heating and cooling in 2000 minus the energy for heating and cooling in 1990 (Table 8) gives the growth of energy between 1990 and 2000:

\[
\begin{align*}
38.50 \text{ quads} & \quad -31.80 \text{ quads} \\
\hline
6.70 \text{ quads}
\end{align*}
\]

This time 25 percent of the new construction uses solar energy. Therefore, 6.70 times 0.25 (Table 9) or 1.675 quads could be produced. Since the process is only 75 percent efficient, 1.675 times 0.75 or 1.256 quads of solar energy will really be produced.

Thus, \((0.735 + 1.256)/38.50\) or 5.17 percent of the heating and cooling energy or \((0.735 + 1.256)/175\) or 1.14 percent of the total energy needs could be supplied by solar energy in that time period.


17. Ronald D. Evans, Chairman of the Department of Mechanical Engineering and Aerospace Sciences, Orlando Florida, 31 January 1975, Personal Files of Michael Armstrong, West Palm Beach, Florida.


